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SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

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SAIL GTS GROUND SYSTEM ANALYSIS

AVIONICS SYSTEM ENGINEERING

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## 1.0 SUMMARY

This paper presents a comparison of two different concepts for the GTS (Guidance, Navigation and Control Test Set) signal ground system. The first is a concept utilizing a ground plate to which Crew Station, Avionics Racks, EPDS (Electrical Power Distribution System), MECCA (Master Electrical Common Connection Assembly) and MMES (Marshall Mated Elements System) grounds are connected by #4/0 welding cable. An alternate approach has an aluminum sheet interconnecting the signal ground reference points between the Crew Station and Avionics Racks. The comparison analysis quantifies the differences between the two concepts in terms of DC resistance, AC resistance and inductive reactance. These parameters are figures of merit for ground system conductors in that the system with the lowest impedance is the most effective in minimizing noise voltage. Although the welding cable system is probably adequate, the aluminum sheet system will provide a higher probability of a successful system design and is recommended.

## 2.0 DISCUSSION

The purpose of this paper is to evaluate and compare two alternate approaches to a signal ground system design for the GTS. Figures 1 and 2 illustrate the two concepts. Calculations are performed in this section for DC resistance, AC resistance and inductive reactance and the results are listed for comparison in paragraph 2.6.

### 2.1 D.C. Resistance

A DC resistance of .0025 ohms is assumed for each connection made since this is the maximum allowable value for RF electrical bonds specified in MIL-B-5087B, Military Specification, Bonding, Electrical and Lightning Protection, for Aerospace System. The maximum value is used since the actual RF impedance of the electrical bonds is difficult to calculate but will certainly be higher than the measured DC value. The welding cable system will then have a total electrical junction resistance of .0075 ohm and the aluminum sheet system will have .005 ohm between Avionics Racks and Crew Station. When the DC resistance of the conductor material is included, (from wire and resistivity tables) the

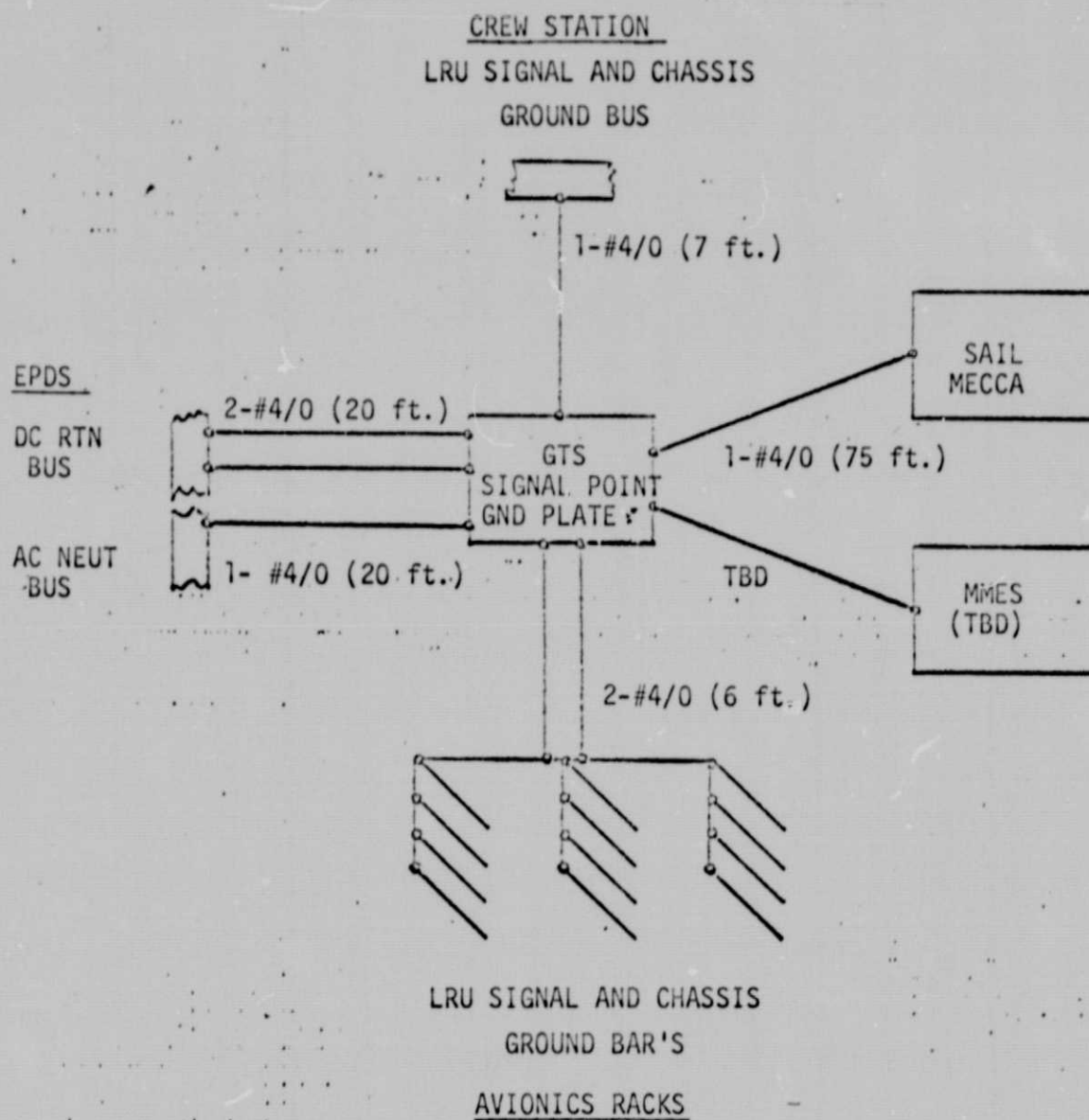


Figure 1: GTS Welding Cable Signal Ground System

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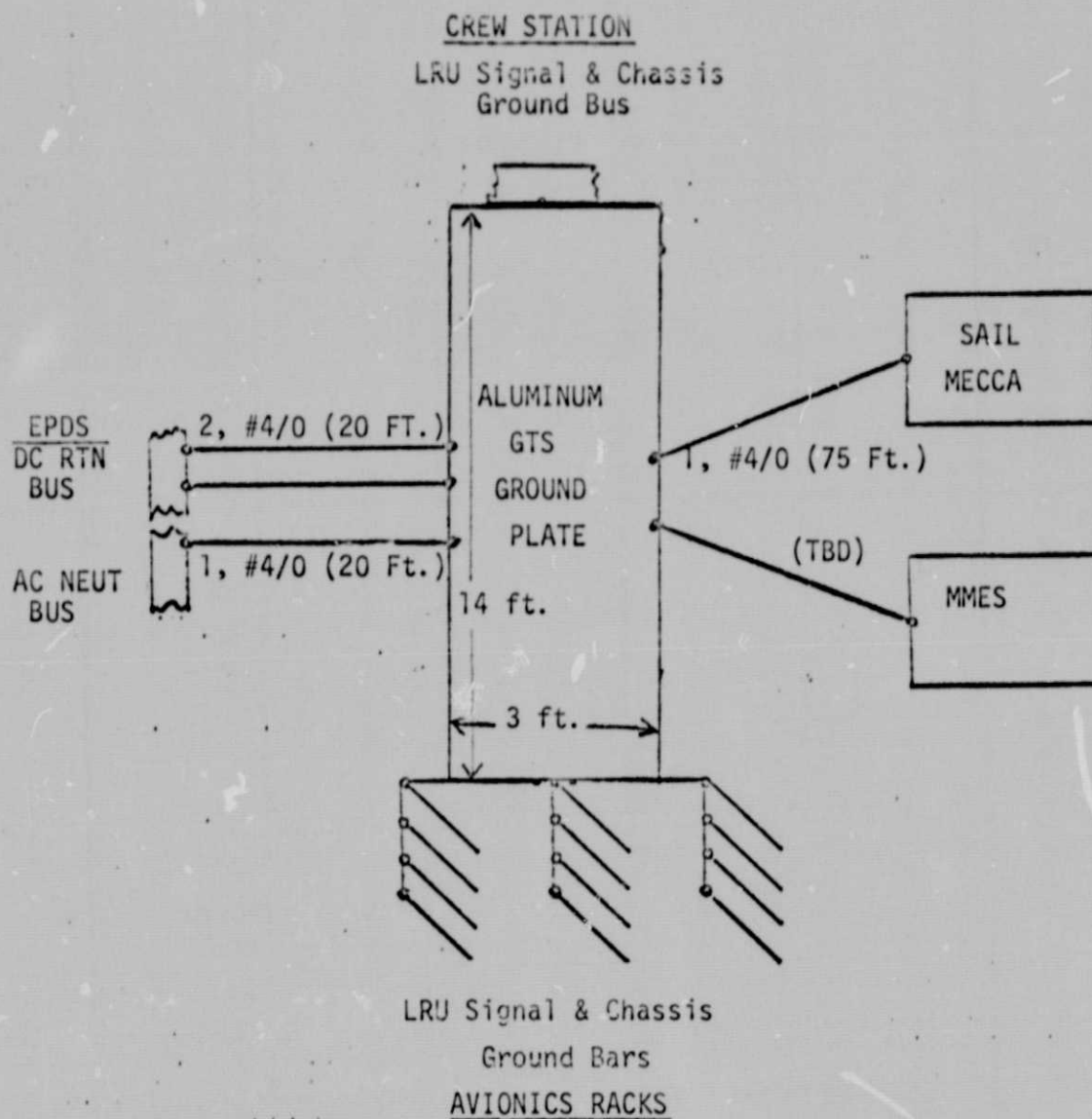


Figure 2: GTS Aluminum Sheet Signal Ground System

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welding cable system DC resistance becomes .0080 ohm and the sheet aluminum system DC resistance is .0050 ohms.

## 2.2 AC Resistance of Cable System

Due to skin effect, any conductor will have, as a function of frequency, an AC resistance higher than the DC resistance. From Reference 1 the AC resistance #4/0 copper welding cable (0.570 inches diameter) is  $1.7515 \sqrt{f} \times 10^{-6}$  ohms/ft. (modified for units change from ohms/cm). Figure 1 shows a 6 ft run of two parallel #4/0 cables between the Avionics Racks and the GTS Ground Plate. The AC resistance of this parallel run then is  $R_{AC} = 5.254 \sqrt{f} \times 10^{-6}$  ohms at 100 MHz = .05254 ohms, at 1 MHz = .005254 ohms.

It should be noted that using two or more cables between the same points in a ground system presents a dilemma. To minimize inductive coupling of noise currents into the resulting ground loop, the two cables should be routed as closely together as possible. However, there is a proximity effect which increases the AC resistance by 33% as the separation distance approaches the cable diameter.

A single #4/0 cable, seven feet long, is connected between the GTS Ground Plate and the Crew Station. Its AC resistance is  $R_{AC} = 1.226 \sqrt{f} \times 10^{-5}$  ohms; at 100 MHz = .1226 ohms, at 1 MHz = .01226 ohms. The AC resistance of the GTS copper ground plate is calculated across the dimension which gives the optimum (lowest) value. It is assumed that the system would be implemented in this manner. The plate dimensions are proposed to be 3/8 inch thick by 36 inches wide by 15 inches long.

From reference 1

$$R_{AC} = \frac{2.05 (3132) \sqrt{f}}{2 (36 + .375)} \times 10^{-9} \text{ ohms/ft} = 88.256 \sqrt{f} \times 10^{-9} \text{ ohms/ft}$$

(Modified for units change from ohms/cm)

For 15 inches (1.25 ft)

$$R_{AC} = 1.1032 \sqrt{f} \times 10^{-7} \text{ ohms; at 100 MHz} = .00110 \text{ ohms, at 1 MHz} = .00011 \text{ ohms.}$$

Total AC resistance of cable and ground plate at 100 MHz = .1762 ohms, at 1 MHz = .0176 ohms.



### 2.3 Inductance of Cable System

With increasing frequency the self - inductance of a straight round wire assumes a limiting value of

$$L = 0.00508 \, l \left( \ln \frac{4l}{d} - 1 \right) \text{ microhenrys}$$

For a section of #4/0 welding cable six feet long

$$L = 1.911 \text{ microhenrys}$$

Inductive reactance  $X_L = 2\pi f L$ ; at 100 MHz = 1200.7 ohms, at 1 MHz = 12.007 ohms

For the two parallel six foot cable segments between the Avionics Racks and the GTS ground plate; at 100 MHz = 600.35 ohms, at 1 MHz = 6.0035 ohms

Inductance of the seven foot cable segment between the GTS ground plate and the Crew Station is

$$L = 2.295 \text{ microhenrys}$$

Inductance reactance

at 100 MHz = 1442.0 ohms, at 1 MHz = 14.420 ohms

For the GTS ground plate inductance,  $l = 15$  inches,  $b = 36$  inches,  $c = .375$  inches

$$L = 0.00508 \, l \left( \ln \frac{2l}{b + c} + 0.5 + 0.2235 \frac{b + c}{l} \right) = 0.06 \text{ microhenrys}$$

$$X_L, \text{ at 100 MHz} = 37.699 \text{ ohms, at 1 MHz} = .37699 \text{ ohms}$$

Total inductive Reactance of cable and ground plate at 100 MHz = 2080.049 ohms  
and at 1 MHz = 20.805 ohm.

## 2.4 AC Resistance of Aluminum Sheet System

The AC resistance of a copper rectangular conductor is

$$R_{AC} = K \frac{261 \sqrt{f}}{2(a+c)} \times 10^{-9} \text{ /cm}$$

K is a factor determined from Reference 1 and is a function of  $\frac{a}{c}$

(a) is the width dimension and (c) is the thickness. For a 36 inch by 1/8 inch sheet,  $K = 2.25$ . Correcting for the resistivity of aluminum vs copper and converting units to ohms/ft yields,

$$R_{AC} = 152.09 \sqrt{f} \times 10^{-9} \text{ ohms/ft}$$

for a sheet 14 ft long,

$$R_{AC} = 2129.26 \sqrt{f} \times 10^{-9} \text{ ohms}$$

at 100 MHz

$$R_{AC} = 0.02129 \text{ ohms}$$

at 1 MHz

$$R_{AC} = 0.002129 \text{ ohms}$$

## 2.5 Inductance of Aluminum Sheet System

Assuming an aluminum sheet 14 ft long (l), 3 ft wide (b), and 1/8 inch thick (c)

$$L = 0.00508 l \left( \ln \frac{2l}{b+c} + 0.5 + 0.2235 \frac{b+c}{l} \right)$$

$$L = 2.371 \text{ microhenrys}$$

$$X_L \text{ at 100 MHz} = 1489.743, \text{ at 1 MHz} = 14.897$$

## 2.6 Impedance Comparison

The table below summarizes and compares the calculated values of DC resistance, AC resistance and inductive reactance for the two systems. For all practical purposes the impedances are equivalent to the inductive reactance.

	<u>Welding Cable System</u>	<u>Aluminum Sheet System</u>
	<u>ohms</u>	<u>ohms</u>
DC Resistance	0.0080	0.0050
AC Resistance		
@ 100 MHz	0.1762	0.0213
@ 1 MHz	0.0176	0.0021
Inductive Reactance		
@ 100 MHz	2080.049	1489.743
@ 1 MHz	20.805	14.897



### 3.0 CONCLUSION

It would appear that the welding cable system is consistent with SAIL grounding practices and is probably adequate. However, since actual RF effects of grounding systems are difficult to predict, the aluminum sheet system is recommended. The probability of a successful system design would be improved with the lower resistance and reactance values.

### 4.0 Reference 1, Radio Engineers Handbook, Frederic Emmons Terman, Sc.D.